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Laboratory Model of Thermal Plant Identification and Control

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Abstract: The real experiments play increasingly a big part in control education. We have been developing plants to be used in the classes for more than three decades. The thermo-opto-mechanical plant TOM1A represents one of the most successful products of this development. This paper presents ways of identification and control of a thermal channel of this plant. In our study programme on Automotive Mechatronics the thermo-opto-mechanical plants are firstly used in an introductory course on Automatic control to interact with basic problems of stability, performance and a plant identification.

Keywords: PID control, performance, robustness, noise attenuation, Matlab/Simulink, interactive tool

Fig. 1. Thermo-opto-mechanical system TOM1A

1. INTRODUCTION

The current version of the plant in Fig. 1 was introduced at the IFAC world congress in 2014 (Huba et al. (2014)). It was designed as an Arduino based innovation of the previous model uDAQ24/T from 2005. However, it still has some of the tricky features, the thermal channel of the plant still is not easy to identify and control during one class session in a simple way.

The temperature control channel uses a bulb as an actuator. It is a common 20W/12V halogen bulb without a reflector. To reduce the demands on the power source and to prevent possible overheating of the device the bulb operates only in the range of 0 to 5W. The plant may be described by nonlinear differential equations. They result from the heat transfer by convection, conduction and radiation and of the nonlinear character of the Stefan-Bolztmann law (Jelenčiak et al., 2007). An example of nonlinear model identification for similar plants has been described in Jelenčiak et al. (2009), which was derived for one of the older versions of the plant however fits the dynamics of the new plant as well.

The dynamics of the thermal channel is dominated by two modes of heat transfer by the radiation and the convection. Therefore a linear plant approximation corresponds to a plant with fast and slow channels treated, for example, by Åström et al. (1998). In Fig.2 the pink arrows correspond to the conduction of the heat via the body of the plant. This process is very slow when compared to the bulb heating the temperature sensor by radiation. The red arrow corresponds to this way of heat transfer. These principally nonlinear modes run in parallel. Second order plant model with relative degree one

$$G_1(s) = \left(\frac{K_1}{T_1 + s} + \frac{K_2}{T_2 + s}\right) e^{-T_d s} \tag{1}$$

can be used to describe locally this plant dynamics. Only one deadtime is considered for simplicity and should be used for the approximation of the sensor and filter dynamics. The slow settling time of the step response makes the plant hard to identify during one laboratory class. The step response of the real plant to the input step realized by bulb power change from 0% to 50% at 1 second can be seen in Fig.3 compared with the model (1) response. It is obvious that the model fits the data quite well. The parameters are $K_1 = 0.26, K_2 = 0.29, T_1 = 40, T_2 = 550, T_d = 0$. This model will be hereafter in the paper denoted as Two Modes. The sampling time of $T_s = 0.5$ was used. The model vs real data comparisons in Figs 3,4,5,6 are modified to start at zero temperature since the experiments do not start at exactly the same temperature level.

Despite the complexity of the thermal process, the students many times consider the temperature channel and its dynamics to be easier to understand than other plant channels. A direct physical interpretation of the solved task makes it less abstract for them than the artificial problem of for instance the filtered light intensity control.

2. FIRST ORDER MODELS

One of the most frequently cited works on PID design by Ziegler and Nichols (1942) integrates the tuning methods with simple plant approximations. In this section, first

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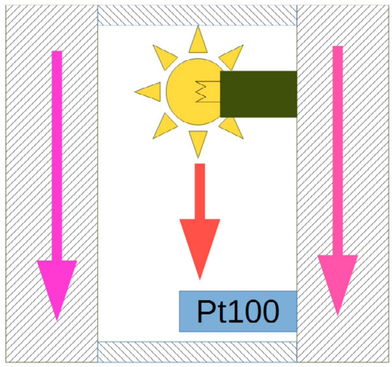

Fig. 2. The heat transfer inside the plant

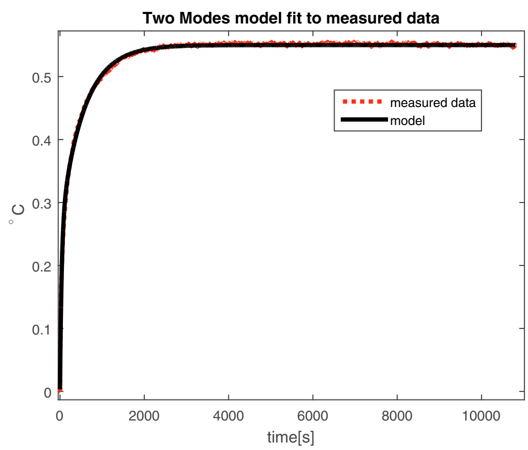

Fig. 3. Approximation of a step response by second order model with relative degree one

order model approximations inspired by this work will be presented focusing on approximation of a chosen segment of the plant step response.

2.1 Integrator plus Dead Time (IPDT) Model

The simplest possible approximation of step responses of the thermal plant may be based on the IPDT model (2). Ziegler and Nichols (1942) proposed such a step response approximation by a tangent to its inflection point. This graphically clear and easy method for a manual identification of the fastest possible output increase is not so simple to implement numerically. Therefore, the script available to the students makes iterations of process parameters and looks for the parameters of the model (2) yielding the longest possible dead time and largest possible plant gain by the least squares method. Appropriate time segment for the approximation, e.g. from 1 to 2.5s, has to be specified by the user. In this paper it resulted in $K_s = 0.01, T_d = 0.38$.

$$G_1(s) = \frac{K_s}{s} e^{-T_d s} \tag{2}$$

Fig.4 shows the model fitting the measured data. Note that the input step start time was set to 1 second.

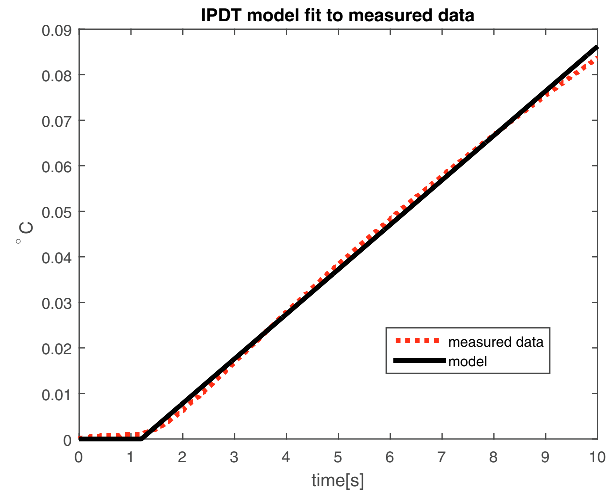

Fig. 4. approximation the beginning of the step response by IPDT model

2.2 First Order plus Dead Time Models

To obtain a more global approximation one would quite naturally use static model (3). In this paper two ways of step response approximation by this model are presented. The first one (FOPDT1) is based on the beginning of the step response (Fig.5).

$$G_1(s) = \frac{K_s}{s+a} e^{-T_d s} \tag{3}$$

The script available to the students iterates to find the longest dead time by the least squares method on a specified time interval. The parameters $K_s = 0.012, a = 0.04, T_d = 0.58$ correspond to the solution in Fig.5. Another first order plus dead time (FOPDT) approximation for the full length of step response that is more reliably matching steady states was obtained for a correspondingly changed approximation interval and is denoted as FOPDT2. The identified parameters $K_s = 0.016, a = 0.029, T_d = 0.35$ show a slight gain increase, but a more significant dead time decrease. Again the input step time was set to 1 second. Fig.6 shows the FOPDT1 and FOPDT2 models fiting the whole step response of the plant. It is obvious that the model FOPDT2 obtained from the whole step response fits the process gain better. However, the FOPDT1 model gain and time constant based on the beginning of the step response are similar to the fast mode parameters in section 1 corresponding to the heat transfer by radiation, which dominates this part of the step response.

3. FILTERED PI CONTROL OF THE PLANT

The PI control based on the linear process models in this paper yielded interesting results. The filtered PI (FPI) control used in this paper considers extension of an ideal one-degree PI controller

$$R(s) = K_c \frac{1+T_i s}{T_i s} \tag{4}$$

by a prefilter with a weighting coefficient b

$$F_p(s) = \frac{1+bT_i s}{1+T_i s} \tag{5}$$